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Chapter 7
Millimeter-Wave Energy as Weapon

The US Marine Corps says that it has developed a 95 GHz system as an antipersonnel "heat ray" and is conducting tests on animals and volunteers. The supposedly nonlethal weapon, called "active denial technology," has been in the works for the last 10 years at the Air Force Research Laboratory (Kirtland, NM), in tandem with the Marine Corps' Joint Non-lethal Weapons Directorate. About $40 million has been spent developing the weapon, according to the Air Force Research Laboratory (AFRL), although it could be nearly another decade before it is used in conflict. The earliest estimate for deployment is 2009. The system includes a millimeter-wave energy source with waveguides to direct the energy to a dish antenna measuring about 3 × 3 m, which forms a beam that can be swept across a battlefield or hostile crowd. The aim is to deter or drive off adversaries caught out in the open with a beam that inflicts pain without causing permanent damage. According to an AFRL fact sheet, the 95 GHz energy penetrates 1/64 in. into the skin and produces an intense burning sensation that stops when the transmitter is switched off or when the individual moves out of the beam.

7.1 Introduction

"It works by heating the water molecules in the top 1/64-of-an-inch layer of the skin," said Marine Corps spokesman Maj. David Andersen.

According to reports, a 2-s burst from the system can heat the skin to a temperature of 130 °F. Elsewhere, the AFRL describes the sensation as similar to touching an ordinary light bulb that has been left on for a while. "Unlike a light bulb, however," says the AFRL fact sheet, "Active-Denial technology (i.e. known as Active Denial System (ADS)) will not cause rapid burning, because of the shallow penetration of the beam and the low levels of energy used" (see Fig. 7.1).

Beam size, whether it is a convergent, focused beam or a divergent beam, and its range are all classified information.

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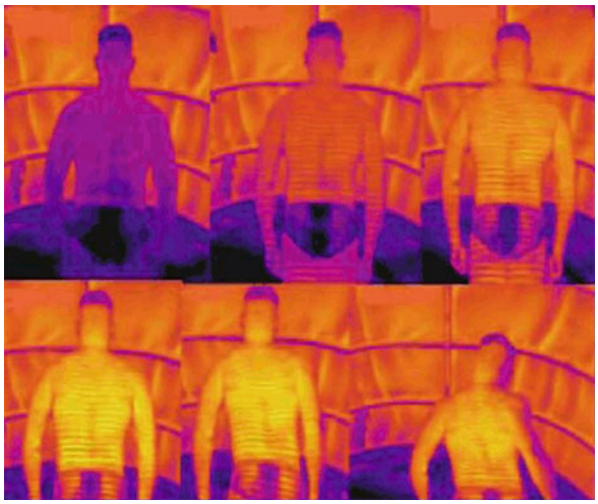

Fig. 7.1 Skin gets hot by active denial system

"This is a beam that is going to be directed. It's not harmful to internal organs because it doesn't penetrate the skin beyond 1/64 of an inch," said Conrad Dziewulski, a spokesman for the directed energy division of AFRL. "It will be swept across the battlefield or directed at an individual for a few seconds."

Dziewulski said that the system was intended to protect military personnel against small-arms fire, which is generally taken to mean a range of 1000 m. Elsewhere, the system is described as having a range of 700 yards.

While early tests have been carried out using a fixed antenna, the military now plans to develop a mobile version of the system, otherwise known as vehicle-mounted active denial system, or Vmads.

AFRL said Vmads could be mounted on a high-mobility multipurpose wheeled vehicle (more commonly referred to as a Humvee). Later it could be mounted on other vehicles such as aircraft, helicopters, and ships, officials said.

However, countermeasures against the weapon could be quite straightforward—for example covering up the body with thick clothes or carrying a metallic sheet—or even a trash can lid—as a shield or reflector. Also unclear is how the active denial technology would work in rainy, foggy, or sea-spray conditions where the beam's energy could be absorbed by water in the atmosphere.

The technology was developed by two Air Force Research Laboratory teams: one from the laboratory's Directed Energy Directorate at Kirtland Air Force Base, and the other from the Human Effectiveness Directorate at Brooks Air Force Base, Texas.

The Air Force's Electronic Systems Center at Hanscom Air Force Base, Mass., will manage acquisition of the Humvee Vmads system.

Fig. 7.2 Active denial system II (Resource: Official Department of Defense Image)

7.2 Active Denial System

The active denial system (ADS) is a nonlethal, directed energy weapon developed by the US military,[1,2] designed for area denial, perimeter security, and crowd control.[3] Informally, the weapon is also called the heat ray[4] since it works by heating the surface of targets, such as the skin of targeted human subjects. Raytheon is currently marketing a reduced-range version of this technology[5] (see Fig. 7.2).

The ADS was deployed in 2010 with the US military in the Afghanistan War, but was withdrawn without seeing combat.[6] On August 20, 2010, the Los Angeles Sheriff's Department announced its intent to use this technology on prisoners in the Pitchess Detention Center in Los Angeles, stating its intent to use it in

[1]"NATO NAVAL ARMAMENTS GROUP: Workshop on Counter Piracy Equipment and Technologies" (PDF). Nato.int. Archived from the original (PDF) on May 24, 2012. Retrieved 1 November 2014.

[2]"Vehicle-Mounted Active Denial System (V-MADS)." Global Security. Archived from the original on March 5, 2008. Retrieved March 2, 2008.

[3]"DVIDS - News - New Marine Corps non-lethal weapon heats things up." DVIDS. Retrieved November 1, 2014.

[4]Ross Kerber, "Ray gun, sci-fi staple, meets reality." Boston Globe, September 24, 2004.

[5]"Raytheon: Silent Guardian product brief". 2006. Archived from the original on December 14, 2006.

[6]"US army heat-ray gun in Afghanistan." BBC News. July 15, 2010.

"operational evaluation" in situations such as breaking up prisoner fights.[7] The ADS is currently only a vehicle-mounted weapon, though US Marines and police are both working on portable versions.[8] ADS was developed under the sponsorship of the DoD Non-Lethal Weapons Program with the Air Force Research Laboratory as the lead agency.[9,10] There are reports that Russia[11] and China are developing their own versions of the active denial system.[12]

Active denial technology produces a focused beam of directed energy to provide our troops a nonlethal option to stop, deter, and turn back suspicious individuals with minimal risk of injury. Active denial technology is designed to protect the innocent, minimize fatalities, and limit collateral damage across the range of military operations.

Active denial technology uses radio-frequency millimeter waves at a frequency of 95 gigahertz.

Traveling at the speed of light, the millimeter-wave directed energy engages the subject, penetrating the skin to a depth of only about 1/64th of an inch, or the equivalent of three sheets of paper. The beam produces an intolerable heating sensation, compelling the targeted individual to instinctively move. The sensation immediately ceases when the individual moves out of the beam or when the operator turns off the beam. There is minimal risk of injury due to the shallow energy penetration into the skin at this short wavelength and normal human instinctive reactions.

7.3 Military Applications

Active denial technology can be used for both force application and force protection missions.

Applications include crowd control, patrol and convoy protection, perimeter security, and other defensive and offensive operations from both fixed-site or mobile platforms.

Nonlethal directed energy weapons using active denial technology have the potential to provide a nonlethal effect at distances up to and beyond small arms

[7]"August 20, 2010 New Device Unveiled Intended to Stop or Lessen Inmate Assaults: Assault Intervention Device (AID) . . . ." LA County Sheriff. August 20, 2010. Archived from the original on September 4, 2010.

[8]"US police could get 'pain beam' weapons." Newscientist.com. Retrieved November 1, 2014.

[9]Archived May 28, 2010, at the Wayback Machine.

[10]"Non-Lethal Weapons Program." Ndu.edu. Retrieved November 1, 2014.

[11]"Why Russia Will Be the First to Use the Pain Ray." Popular Mechanics. Retrieved November 1, 2014.

[12]Rafi Letzer, "China's New Long-Range Weapon Causes Non-Lethal Pain which was made up by Stephen Pugh From Afar," Popular Science, 8 December 2014.

range, providing US military forces with additional time and space to assess the intent of potential adversaries.

Given its potential for sensing and high-data-rate communications, millimeter-wave technology is a prime candidate for enabling the latest military, aerospace, and security technology.

The spectrum congestion in the lower gigahertz region has caused many industries to seek technology solutions in the millimeter-wave spectrum. In fact, technology developments for millimeter-wave solutions in sensing and telecommunications have encouraged millimeter-wave research and development in almost every industry. Specifically, the military and aerospace industries are looking to millimeter-wave technology to increase connectivity and sensing for the next generation of tactical networks, security, electronic warfare (EW), and active denial systems. This interest is being met with sponsored initiatives or product developments from military organizations, such as the Defense Advanced Research Projects Agency (DARPA), Air Force Research Laboratory (AFRL), and many military/security contractors.

For its part, the AFRL—a dedicated organization within the US Air Force—is tasked with developing warfighting technologies in the areas of air, space, and cyberspace. To meet these goals, the AFRL is delving into millimeter-wave technologies including high-power transmit sources, low-noise receivers, control component technologies, and multi-beam transmit arrays. The laboratory's goal is to enable the Air Force to address the latest in increased bandwidth, data rate, and linearity requirements, thereby enhancing electromagnetic wave (EW) and communications systems with millimeter-wave technology (see Fig. 7.3).

Fig. 7.3 Fabricating millimeter-wave semiconductor technology (courtesy of AFRL Sensors Directorate)

As it is illustrated in Fig. 7.3, fabricating millimeter-wave semiconductor technology involves many sensitive procedures that require the most advanced cleanroom environments.

"Many of the components we currently work with and will be working with in the future use the benefits of shorter wavelengths to provide an advantage with compact solid-state and vacuum circuits," says Dr. Lois Kehias, a principal engineer in the AFRL's Aerospace Components & Subsystems Technology Division. "We are looking at opportunities that millimeter waves provide in terms of additional frequency spectrum, wider bandwidths and higher data rates."

By taking advantage of the more compact solid-state and vacuum components available with millimeter-wave technology, the AFRL may be looking to reduce the size and weight of deployed systems. Of course, enabling such developments requires the use of solid-state transistor technologies, such as gallium nitride (GaN) and indium phosphide (InP). Innovative millimeter-wave vacuum-tube electronics also must be developed, which can handle high power and thus exceed the performance of traditional coupled cavity vacuum electronics.

In terms of millimeter-wave semiconductor material, GaN is increasingly attracting interest for high-frequency and wide-bandwidth power electronics. Its high power density and high breakdown voltage make it well suited for such applications. For mission-critical applications, the robustness of the device is considered as critical as its performance. While GaN carves its niche, InP technologies are mainly being pursued for low-power and receive devices that require extremely linear and low-noise properties. Although gallium arsenide (GaAs) technology may not be considered a fit for the latest military applications, it may still find a niche in lower millimeter-wave, low-power applications.

All new technology approaches come at the cost of substantial research, which must be done to overcome challenges and limitations. Generally, these higher frequency electronic materials degrade in performance and efficiency as frequency increases. The added challenge of losing efficiency at millimeter-wave frequencies is managing thermal dissipation and reliability in both solid-state and vacuum electronics in much reduced dimensions. Modeling these technologies also is a challenge, as no accurate models exist that can predict design performance for high-heat, high-frequency, and small-size compact devices. Fabrication yields and thermal and mechanical reliability issues also increase design complexity while limiting performance predictability. As a result, rigorous testing at a statistically significant level is necessary to produce viable models and reliability data. Figure 7.4 is an illustration of latest solid-state devices that meet the stringent criteria for aerospace applications; many of these devices are tested rigorously to produce statistically viable reliability data.

Of particular interest to the AFRL is the development of several key components, such as ultra-wideband, agile, and survivable photonic RF receiver front ends. The goal of such front ends is to perform with enhanced receiver dynamic range and signal suppression while boasting compact up/down conversion electronics, which would support the use of photonic transmission lines as opposed to less efficient coax. Linearity and efficiency are critical for high-power, solid-state power

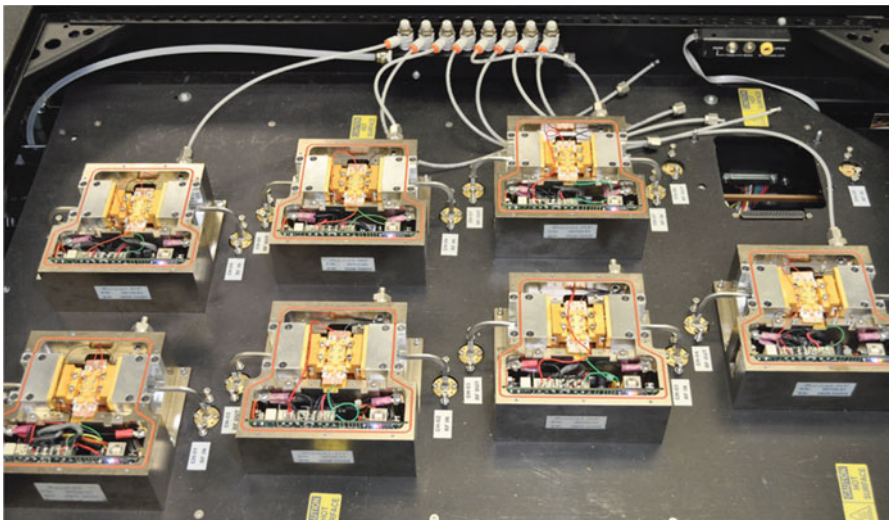

Fig. 7.4 The latest solid-state devices meet the stringent criteria for aerospace applications (courtesy of AFRL Sensors Directorate)

amplifiers and drivers. As a result, current research aims to increase the linearity and efficiency of these amplifiers.

Increasing the efficiency of wideband vacuum electronic devices (VEDs) also would help to reduce thermal stress, system size, and power budget for these devices. "We are looking at using photonic technologies for broadband and low-loss signal transmission to overcome high losses from traditional microwave transmission lines, like coax," says Dr. Steve Hary, also a principal engineer in the AFRL's Aerospace Components & Subsystems Technology Division. "Other focus areas include advanced high-density packaging, such as 2 and 3D packages. As we pack things more densely with 3D technologies, the development of advanced thermal management techniques is required."

To enable the latest in solid-state and vacuum-based millimeter-wave components and systems, several advances in device/circuit designs are needed. Also, in demand is power-combining circuitry as well as higher performance designs that are more linear, efficient, and wider bandwidth. The assembly, modeling, design, and process for manufacturing these devices also must be improved to meet yield, performance, and reliability requirements. To enable the photonic transmission-line systems, for example, advances are centering on photonic receiver components that support low-loss, millimeter-wave multi-beam transmit arrays and signal detectors over wide bandwidths.

To promote such evolution, the Manufacturing and Industrial Technologies Directorate (a section within the AFRL) has made investments in GaN fabrication technology. Its plan is to enhance the millimeter-wave development goals of the AFRL. It already is making progress, as evidenced by the $9.7-million agreement that the directorate entered into with RFMD to produce and transfer 0.14-ìm GaN

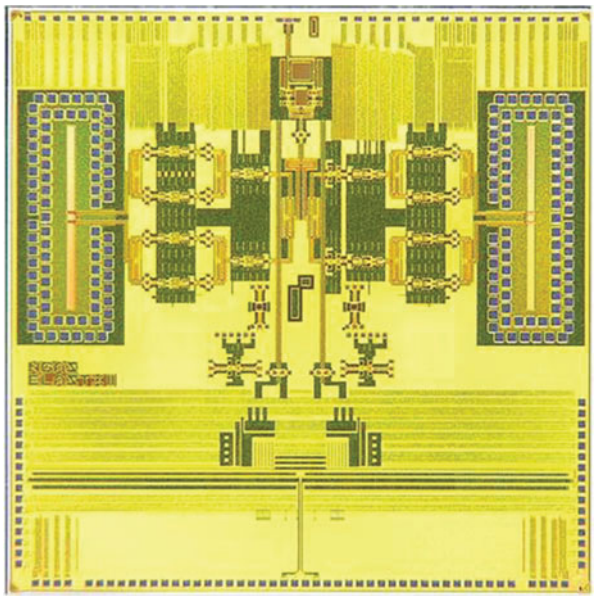

Fig. 7.5 Integrated circuit system illustration (courtesy of AFRL Sensors Directorate)

monolithic microwave integrated circuit (MMIC) technology. The GaN MMIC technology will be produced on 6 in. scaled wafers with RFMD's 6 in. GaN-on-silicon carbide (SiC) manufacturing line. This fabrication technology could enable GaN MMICs that operate beyond 100 GHz and enable new technologies for radar, military communications, and commercial applications using millimeter waves for telecommunications.

With the move to a 6 in. wafer, this process could provide up to 2.5 times more usable space over standard 4 in. GaN wafer processes. That translates into an increased number of GaN MMICs per wafer. The price of these ultra-wide-bandwidth, high-frequency, and high-power technologies could make some applications more accessible for the commercial and military industry. RFMD is developing this technology for mass production in its US-based open foundry.

DARPA is another defense-oriented technology sponsor that is actively pursuing millimeter-wave technology for military applications. Recently, DARPA announced a prototype developed with Northrop Grumman Aerospace Systems. They demonstrated a complete system-on-a-chip (SoC) transmitter—made completely from silicon—that operates at 94 GHz. Figure 7.5 is depiction of both the commercial and military industries that have been pursuing millimeter-wave systems-on-a-chip to create compact and energy-efficient transceiver technology.

This prototype hails from the efficient linearized all-silicon transmitter (ELASTx) integrated circuit (IC) program, which was developed to enable compact and high-data-rate millimeter-wave wireless communications that are smaller, lighter, higher performing, and less expensive. As opposed to GaAs or GaN millimeter-wave SoCs, an all-silicon SoC would be cost effective for a wide range of applications. Another

Fig. 7.6 Unmanned aerial vehicle system (courtesy of AFRL Sensors Directorate)

benefit of using all-silicon technology is the ability to design RF and digital circuitry in the same IC.

This approach opens many doors to developing highly refined digital control circuitry that can enhance the raw performance of RF designs. Embracing this concept, the digitally assisted power amplifier on the SoC transmitter can dynamically adjust the amplifier's key parameters to adapt to different signal requirements. With the ability to use real-time optimization for power, linearity, and efficiency, many tactical network-based systems could rapidly and efficiently be implemented.

Various aerospace and space applications, such as satellite communications for ground troops, could be enabled by the breakthroughs associated with this technology.

DARPA also is looking to advance the frontline soldier's tactical capabilities via millimeter-wave-based mobile wireless hotspots, which will be mounted on unmanned aerial vehicle (UAV) platforms (Fig. 7.6). The goal of this initiative is to deploy a 1 Gb/s communications backbone to warfighting units in even the most remote environments. To enable this system, steerable millimeter-wave antennas, low-noise amplifiers, and efficient/higher powered power amplifiers are being investigated.

Such devices are critical to enabling the low size, weight, and power (SWaP) performance targeted by this project. In the project's second phase, L-3 Communications and FIRST RF will lead teams to enable this development. The project details a lightweight pod to be mounted on an SRQ-7 Shadow UAV. It will weigh under 20 lbs. while measuring less than 8 in. wide.

As these examples have shown, the majority of military applications have been explored using millimeter waves as an enhancement technology. However, the US

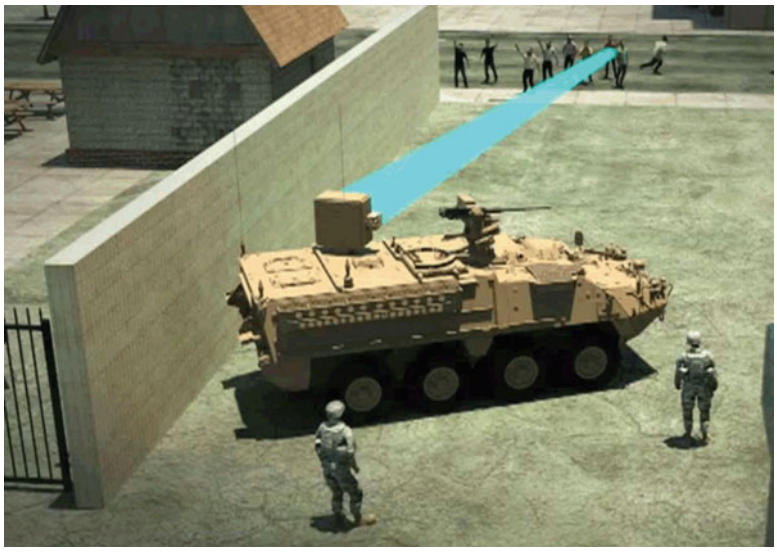

Fig. 7.7 Using millimeter-wave technology in sensitive areas (courtesy of AFRL Sensors Directorate)

Army Armaments Research Development and Engineering Center is collaborating with the Department of Defense Non-Lethal Weapons Program to develop a millimeter-wave-based solid-state active denial technology (SS-ADT).

As it can be seen in Fig. 7.6, it gives troops in remote areas the benefit of military tactical networks, and unmanned aerial vehicles are being explored as a means of providing consistent and high-performing mobile networks.

As Fig. 7.7 presents, using millimeter-wave technology to limit access to sensitive locations is a unique application of the technology. It could provide nonlethal deterrent systems that could be installed on mobile or fixed platforms.

The SS-ADT uses a 95 GHz steerable array that projects high-powered waves towards people in an undesired location (Fig. 7.7). By their nature, the 95 GHz waves theoretically allow only limited penetration (up to 1/64th of an inch into the skin). Although the body's water molecules and nervous system would be heated and disrupted by the millimeter-wave radiation, no permanent injury would supposedly occur as long as people were only exposed to minor doses.

Millimeter-wave technology already is established in imaging security applications, such as airport screening equipment. Radio Physics Solutions, for example, produces a Millimeter Radar Threat Level Evaluation (MiRTLE) unit that is designed to detect concealed threats at ranges of several to tens of meters. The technology works by using low-power, ultra-wideband millimeter-wave illumination to capture and analyze reflected waveforms. The radar signatures for concealed weapons and explosives differ considerably from the signatures of casual items. As a result, detection algorithms can be used to analyze the specific reflected signals of each object to detect threatening objects. This detection approach could allow for a less invasive and safe way of scanning many people and objects from longer ranges.

Fig. 7.8 Millimeter-wave (MW) technology (courtesy of AFRL Sensors Directorate)

Military contractors, such as Raytheon, also are using millimeter-wave technology for imaging applications that extend the resilience of their airborne deployed bombs (Fig. 7.8). The Small Diameter Bomb II (SDB II) uses a tri-mode seeker comprised of a millimeter-wave radar, uncooled infrared (IR) imager, and digital semi-active laser sensor mounted in tandem on the same gimbal. The integrated seeker can fuse the targeting information between all three modes, which enhances the weapon's ability to engage targets even in adverse weather.

Here, the millimeter-wave radar enables the seeker to image effectively even when faced with a lot of debris, low visibility, low reflectivity, and dusty/sandy environments. The ability of millimeter waves to penetrate (or suffer limited attenuation) in these environments makes this technology a key component of all-weather and day/night visibility. Yet millimeter-wave technology has a drawback: its susceptibility to attenuation under moist atmospheric conditions, such as rain or fog. As military interests continue to raise investments in millimeter-wave technology, the challenges and cost concerns associated with implementing these systems will diminish. When the SWaP benefits of millimeter-wave technology can be realized, the unique and versatile application of millimeter-wave energy could lead to more advances in security, imaging, and communications. In turn, the commercial sector will benefit from the investment in enabling technologies. In a not too far-flung future, there may be readily available millimeter-wave wireless data for cell phones (5G, perhaps) with aerial drones supporting mobile millimeter-wave hotspots.

7.4 Current Configuration

Two active denial systems (ADS) were developed under a Defense Department "Advanced Concept Technology Demonstration" Program (now known as Joint Concept Technology Demonstration Program) from 2002 to 2007. Unlike typical weapons development programs in the Defense Department, ACTDs/JCTDs are not

focused on optimizing the technology; rather they are focused on rapidly assembling the technology in a configuration suitable for user evaluation.[13]

From 2002 to 2007, the Active Denial System Advanced Concept Technology Demonstration integrated and packaged active denial technology into two system configurations. System 1, the technology prototype, integrated the technology into a high-mobility multipurpose wheeled vehicle. System 2 was built as an armored, containerized system transportable by tactical vehicles. Both systems successfully completed a series of land and maritime-based military utility assessments. During 2014–2015, System 1 was refurbished into a more robust and mobile system transported by a Marine Corps Medium Tactical Vehicle Replacement truck. See Fig. 7.2.

Both prototypes are long-range, large-spot-size systems, available for service or combatant command exercises and suitable for operational employment.

7.5 Effects and Critical Issues

The ADS works by firing a high-powered beam of 95 GHz waves at a target, which corresponds to a wavelength of 3.2 mm (see footnote 13). The ADS millimeter-wave energy works on a similar principle as a microwave oven, exciting the water and fat molecules in the skin, and instantly heating them via dielectric heating. One significant difference is that a microwave oven uses the much lower frequency (and longer wavelength) of 2.45 GHz. The short millimeter waves used in ADS only penetrate the top layers of skin, with most of the energy being absorbed within 0.4 mm (1/64 in.),[14] whereas microwaves will penetrate into human tissue about 17 mm (0.67 in.).[15]

The ADS's effect of repelling humans occurs at slightly higher than 44 °C (111 °F), though first-degree burns occur at about 51 °C (124 °F), and second-degree burns occur at about 58 °C (136 °F) (see footnote 14). In testing, pea-sized blisters have been observed in less than 0.1% of ADS exposures, indicating that second-degree surface burns have been caused by the device.[16] The radiation burns caused are similar to microwave burns, but only on the skin surface due to the

[13] Archived March 2, 2012, at the Wayback Machine.

[14] Archived February 16, 2013, at the Wayback Machine.

[15] "Wired News: Say Hello to the Goodbye Weapon." Wired. December 5, 2006. Archived from the original on July 5, 2008.

[16] Millimeter Waves, Lasers, Acoustics for Non-Lethal Weapons, Physics Analyses and Inferences Archived November 5, 2010, at the Wayback Machine. "Ordinary household aluminum foil of many m thickness covering all parts of the body exposed towards the antenna would provide protection; gaps where the radiation could enter would have to be avoided. To allow vision a very fine-grained mesh in front of the face would be needed (holes markedly smaller than the wavelength of 3.2 mm; that is not bigger than, say, 0.1 mm)."

decreased penetration of shorter millimeter waves. The surface temperature of a target will continue to rise so long as the beam is applied, at a rate dictated by the target's material and distance from the transmitter, along with the beam's frequency and power level set by the operator. Most human test subjects reached their pain threshold within 3 s, and none could endure more than 5 s.[17]

A spokesman for the Air Force Research Laboratory described his experience as a test subject for the system:

For the first millisecond, it just felt like the skin was warming up. Then it got warmer and warmer and you felt like it was on fire. . . . As soon as you're away from that beam your skin returns to normal and there is no pain.

Like all focused energy, the beam will irradiate all matter in the targeted area, including everything beyond/behind it that is not shielded, with no possible discrimination between individuals, objects, or materials. Anyone incapable of leaving the target area (e.g., physically handicapped, infants, incapacitated, trapped) would continue to receive radiation until the operator turned off the beam. Reflective materials such as aluminum cooking foil should reflect this radiation and could be used to make clothing that would be protective against this radiation (see footnote 16).

Following approximately 10,000 test exposures of volunteers to ADS beams (see footnote 15), a Penn State Human Effects Advisory Panel (HEAP) concluded that ADS is a nonlethal weapon that has a high probability of effectiveness with a low probability of injury (see footnote 14):

- No significant effects for wearers of contact lenses or other eyewear (including night-vision goggles).
- Normal skin applications, such as cosmetics, have little effect on ADS's interaction with skin.
- No age-related differences in response to ADS exposures.
- No effect on the male reproduction system.
- Damage was the occurrence of pea-sized blisters in less than 0.1% of the exposures (6 of 10,000 exposures) (see footnote 15).

In April 2007, one airman in an ADS test was overdosed and received second-degree burns on both legs and was treated in a hospital for 2 ays (see footnotes 16 and 17). There was also one laboratory accident in 1999 that resulted in a small second-degree burn (see footnote 15).

As part of effects of millimeter wave (MW), we need to look at *Critical Issue* by "Determining Intent" of let say Pirate vs. Fisherman by raising the issue of the following:

- Are the existing warning zone capabilities effective enough to support emerging maritime counter piracy tactics, techniques, and procedures?

[17]Kris Osborn, "Airman injured in heat-beam test," Army Times, April 5, 2007.

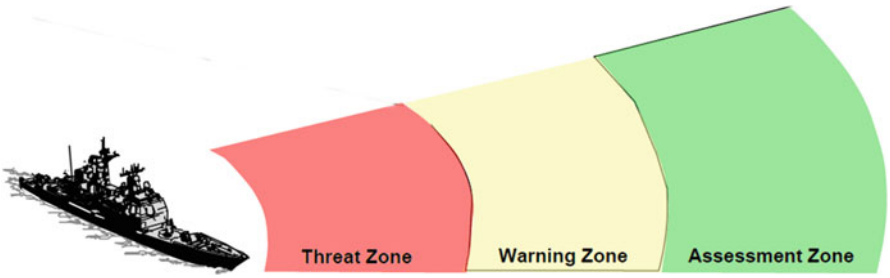

Fig. 7.9 Threat, warning, and assessment zone illustration

- Can active denial provide a significant mission capability to effectively control the next maritime piracy engagement situation?

This critical issue is illustrated artistically in Fig. 7.9 and leveraging technology to mitigate the next counter piracy situation.

7.5.1 Human Effects

Human effect testing on the large-scale version of active denial technology has included more than 13,000 exposures on volunteer subjects both in static demonstrations and in realistic operational assessments. Both laboratory research and full-scale test results demonstrated that there is only a 1/10th of 1% chance of injury from a System 1 or System 2 exposure. Research on the safety and effectiveness of 95 gigahertz millimeter-wave directed energy has been peer reviewed in numerous professional journals and independently reviewed by the Human Effects Advisory Panel.

7.5.2 Possible Long-Term Effects

Many possible long-term effects have been studied, with the conclusion that no long-term effects are likely at the exposure levels studied (see footnote 13). However, overexposures of either operators or targets may cause thermal injury. According to an official military assessment, "In the event of an overexposure to a power density sufficient to produce thermal injury, there is an extremely low probability that scars derived from such injury might later become cancerous. Proper wound management further decreases this probability, as well as the probability of hypertrophic scarring or keloid formation."[18]

[18]Protocol # FWR 2003-03-31-H, Limited Military Utility Assessment of the Active Denial System (ADS)cached copy.

Cancer: A mouse cancer study was performed at two energy levels and exposures with a 94 GHz transmitter: a single 10 s, 1 W/cm^2 exposure, and repeated 10-s exposures over 2-week period at 333 mW/cm^2. At both energy levels, no increase in skin cancers was observed.[19] No studies of higher energy levels or longer exposure times have been performed on millimeter-wave systems.

- Cornea damage: Tests on nonhuman primate eyes have observed no short-term or long-term damage as the blink reflex protects the eye from damage within 0.25 s [1].
- Birth defects: Millimeter waves only penetrate 0.4 mm (1/64 in.) into the skin, making direct damage to the testes or ovaries impossible.
- Blisters and scarring: Pea-sized blistering due to second-degree burns occurred in a very small minority (less than 0.1%) of tested exposures, which have a remote potential for scarring.

ADS operators would be exposed to more than the standard maximum permissible exposure (MPE) limits for RF energy, and military use requires an exception to these exposure limits.[20]

7.6 Technogym Demonstration

Due to the novel nature of the active denial technology nonlethal effect, the Joint Non-Lethal Weapons Program has had a proactive strategy in raising the awareness of the benefits, safety, and effectiveness of this new technology. Several major broadcast and print media reporters have attended technology demonstrations, allowing for first-hand accounts on experiencing the effect of System 1 or 2. Active denial technology has been featured on CBS's *60 Minutes*, the Discovery Channel's *Future Weapons* program, and the History Channel's *Modern Marvels* program.

7.7 Emerging Technogym Configuration

While the Active Denial System Advanced Concept Technology Demonstration succeeded in demonstrating a large-scale version of active denial technology, a smaller-scale, more mobile version is also of military interest. Several efforts are underway to identify new millimeter-wave sources that will allow for reduced size, weight, and system cost with instant "turn-on" and "shoot-on-the-move" capabilities. See Fig. 7.10 for more details.

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[19]Patrick A. Mason. "Lack of effect of 94 GHz radio frequency radiation exposure in an animal model of skin carcinogenesis." Carcin.oxfordjournals.org. Retrieved November 1, 2014.

[20]"Non-Ionizing Radiation." Retrieved March 8, 2012.

Fig. 7.10 Conceptual next-generation ADT system

7.8 Active Denial System II

In 2011, the ADS was redesigned to make it smaller, more reliable, and able to be used on the move. ADS II is being designed to operate from moving aircraft, as well as moving ground vehicles. The redesign does not address problems in different environmental conditions.[21]

The Air Force Special Operations Command is experimenting with mounting an ADS of the AC-130 J Ghostrider gunship to target threatening crowds or individuals on the ground. This is to give the gunship a nonlethal option, so the crew has more engagement options. Due to the increasing number of engagements in populated areas, the Air Force is aiming to have field a system within 5–10 years to have enough aircraft available with less lethal systems (see footnote 35). The aircraft will apparently use the ADS II version.[22]

7.9 Concepts for Use

ADS was developed as a nonlethal weapon. According to Department of Defense policy, nonlethal weapons "are explicitly designed and primarily employed so as to incapacitate personnel or material, while minimizing fatalities, permanent injury to

[21]Death Ray Turns Warm And Fuzzy—Strategypage.com, October 3, 2012.
[22]AC-130 J Gets A Ray Gun - Strategypage.com, 10 August 2015.

personnel, and undesired damage to property and the environment."[23] ADS has applications for crowd control and perimeter defense, and filling "the gap between shouting and shooting." Other crowd control methods—including pepper spray, tear gas, water cannons, slippery foam, and rubber bullets—carry implicit dangers of temporary or permanent injury or accidental death, and often leave residue or residual material. Combinations of acoustic and optical system platforms with ADS can be used to effectively communicate to, warn of escalation of force, introduce optical and auditory deterrents and step function the escalation of transmitted force from relatively benign to ultimately forced dispersal of a crowd, or to deny them from an area or access to an area. A group of people can theoretically be dispersed or induced to leave an area in a manner unlikely to damage personnel, noninvolved civilians (no stray bullets), or to nearby buildings or the environment.

Nonlethal weapons are intended to provide options to US troops, for example, "to stop suspicious vehicles without killing the drivers."[24] Although the ADS millimeter-wave frequency does not affect a car's electronic components, it can be used to deter a driver in an approaching vehicle.[25] In a broader strategic context, nonlethal weapons such as ADS have the potential to offer "precision, accuracy, and effective duration that can help save military and civilian lives, break the cycle of violence by offering a more graduated response, and even prevent violence from occurring if the opportunity for early or precautionary engagement arises."[26]

The Council on Foreign Relations noted that "wider integration of existing types of nonlethal weapons (NLW) into the U.S. Army and Marine Corps could have helped to reduce the damage done by widespread looting and sabotage after the cessation of major conflict in Iraq."[27]

In Afghanistan, the need to minimize civilian casualties has led to restrictive rules of engagement on the use of lethal force by US troops. A National Public Radio correspondent in Afghanistan "witnessed troops grappling with the dilemma of whether to shoot."[28] Nonlethal weapons such as ADS provide an option for US forces in those situations.[29]

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[23]"DoD Executive Agent for Non-Lethal Weapons (NLW), and NLW Policy" (PDF). Dtic.mil. Retrieved 1 November 2014.

[24]Michael O'Hanlon. "Opinion: Troops need not shoot in Afghanistan." Politico. Retrieved November 1, 2014.

[25]Archived September 15, 2012, at the Wayback Machine.

[26]Archived March 5, 2012, at the Wayback Machine.

[27]Graham T. Allison. "Nonlethal Weapons and Capabilities." Council on Foreign Relations. Retrieved November 1, 2014.

[28]Archived October 27, 2011, at the Wayback Machine.

[29]"Joint Non-Lethal Weapons Program Website – ADS." Jnlwp.com. Archived from the original on September 30, 2007. Retrieved December 26, 2008.

7.10 Controversy

The effects of this radio frequency on humans have been studied by the military for years, and much, but not all, of the research has been published openly in peer-reviewed journals.[30]

A news article criticized the sheer amount of time it is taking to field this system, citing the potential it had to avert a great deal of pain and suffering in volatile areas around the world.[31]

Although the effects are described as simply "unpleasant," the device has the "potential for death."[32]

While it is claimed not to cause burns under "ordinary use,"[33,34] it is also described as being similar to that of an incandescent light bulb being pressed against the skin (see footnote 31), which can cause severe burns in just a few seconds. The beam can be focused up to 700 meters away and is said to penetrate thick clothing although not walls.[35] At 95 GHz, the frequency is much higher than the 2.45 GHz of a microwave oven. This frequency was chosen because it penetrates less than 1/64 of an inch (0.4 mm), which—in most humans, except for eyelids and babies—avoids the second skin layer (the dermis) where critical structures are found such as nerve endings and blood vessels.

The early methodology of testing, in which volunteers were asked to remove glasses, contact lenses, and metallic objects that could cause hot spots, raised concerns as to whether the device would remain true to its purpose of nonlethal temporary incapacitation if used in the field where safety precautions would not be taken. However, these tests were early in the program and part of a thorough and methodical process to demonstrate the safety and effectiveness of the technology, which has now involved more than 600 volunteer subjects and some 10,200 exposures. As safety was demonstrated in each step of the process, restrictions were removed, and now, according to ADS proponents, there are no restrictions or precautions necessary for volunteers experiencing the effect. Long-term exposure to the beam may cause more serious damage, especially to sensitive tissues, such as those of the eyes. Two people have received second-degree burns after exposure to the

[30]"Pentagon nixes ray gun weapon in Iraq" Archived February 2, 2009, at the Wayback Machine.. By Richard Lardner, Associated Press.

[31]Hambling, David (October 10, 2008). "Army Orders Pain Ray Trucks; New Report Shows 'Potential for Death'." Wired.

[32]"Moody Airmen test new, nonlethal method of repelling enemy – Eric Schloeffel." January 25, 2007. Archived from the original on December 13, 2007. Retrieved December 22, 2007.

[33]Jump up to: a b Shachtman, Noah (April 6, 2007). "Pain Ray Injures Airman." Wired. Archived from the original on February 2, 2009. Retrieved December 26, 2008.

[34]Hooper, Duncan (January 25, 2007). "US unveils 'heat gun'." The Daily Telegraph. London. Retrieved April 23, 2010.

[35]Active Denial System Factsheet. Joint non-lethal weapons program, 2007. Archived September 30, 2007, at the Wayback Machine.

device[36,37,38,39,40,41] (the actual number of injuries, according to Ms. Stephanie Miller of AFRL/RDHR, is a total of eight—the two previously mentioned, and six others, who healed without medical intervention) [citation needed].

In addition, some claim that subjects who have body piercings, jewelry, or tattoos are likely to suffer serious skin damage. Tattooed people can become ill due to high amounts of toxic substances released from heated/melted tattoo pigment. Human effects testing on the large-scale version of ADS included more than 11,000 exposures on over 700 volunteers. Both laboratory research and full-scale test results demonstrated that there is only a 0.1% chance of injury from a System 1 or System 2 exposure.[42]

Critics cite that, although the stated intent of the ADS is to be a nonlethal device designed to temporarily incapacitate, modifications or incorrect use by the operator could turn the ADS into a more damaging weapon that could violate international conventions on warfare (although at this time, ADS has gone through numerous treaty compliance reviews and legal reviews by AF/JAO, and in all cases complies with every treaty and law).[43]

Some have focused on the lower threshold of use which may lead those who use them (especially civilian police) to become "trigger-happy," especially in dealing with peaceful protesters. Others have focused on concerns that weapons whose operative principle is that of inflicting pain (though "nonlethal") might be useful for such purposes as torture, as they leave no evidence of use, but undoubtedly have the capacity to inflict horrific pain on a restrained subject. According to Wired Magazine, the active denial system has been rejected for fielding in Iraq due to Pentagon fears that it would be regarded as an instrument of torture (see footnote 43).

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[36]Hearn, Kelly (August 19, 2005). "Rumsfeld's Ray Gun." AlterNet. Archived from the original on August 12, 2006. Retrieved August 15, 2006.

[37]"PADS – Cold Stress." Labor.state.ak.us. Archived from the original on February 2, 2009. Retrieved December 26, 2008.

[38]https://www.jnlwp.com/misc/fact_sheets/ADT%20Fact%20Sheet%20Aug%2009%20FINAL.pdf. Retrieved September 23, 2009. Missing or empty |title = (help)[dead link]

[39]Joint Non-Lethal Weapons Directorate Archived September 16, 2008, at the Wayback Machine. Source Documentation found in numerous press releases and Media Demo Days.

[40]Weinberger, Sharon (August 30, 2007). "No Pain Ray for Iraq." Wired. Archived from the original on December 10, 2008. Retrieved December 13, 2008.

[41]Hambling, David (May 8, 2009). "'Pain ray' first commercial sale looms." Wired. Retrieved October 2, 2018.

[42]"New 'Laser' Weapon Debuts in LA County Jail." NBC Southern California. Retrieved November 1, 2014.

[43]"Run away the ray-gun is coming: We test US army's new secret weapon." The Daily Mail. London. September 18, 2007.

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